COSMIC DEUTERIUM OR A HYDROGEN INTERLOPER?

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Summary

Two groups have independently reported the possible detection of extragalactic deuterium in the absorption spectrum of the same high redshift, low metalicity QSO. Although the high value for the inferred deuterium abundance poses no problems for cosmology (i.e., big bang nucleosynthesis), it is in apparent conflict with solar system observations of deuterium and helium-3. This latter inconsistency is explained and made quantitative and it is shown that, unless the inferred D/H ratio is too high by a factor of three, these data challenge our understanding of the stellar and galactic evolution of helium-3. This conflict is resolved if the observed absorption feature is, in fact, due to a hydrogen interloper rather than to high z, low Z deuterium.

The observed expansion of the Universe and the presence of the cosmic background radiation ensure that, during its early evolution, the Universe passed through a hot, dense epoch when nuclear reactions synthesized the light nuclides (deuterium, helium-3, helium-4 and lithium-7). In the context of standard Big Bang Nucleosynthesis (BBN), deuterium (D) and helium-3 (^3He) are rapidly burned to helium-4 (^4He) and, the higher the nucleon density (measured by η, the present ratio of nucleons to photons; $\eta_{10} \equiv 10^{10}\eta$), the more

rapidly is D (and ^3He) consumed. Thus, the cosmic abundance of deuterium provides a sensitive probe of the universal density of nucleons (Reeves et al. 1973). Of the light elements, D is unique in that BBN is the only astrophysical site for its production in amounts comparable to those observed (Epstein, Lattimer & Schramm 1976). But, whenever interstellar gas is incorporated in stars, D is destroyed by nuclear burning. As a result, a lower bound to the cosmic abundance of D provides a lower bound to its primordial abundance from which we may infer an upper bound to η (Reeves et al. 1973).

In the course of Galactic evolution, as more gas passes through new generations of stars, D is burned to ^3He. However, not all pre-stellar ^3He is consumed, with the result that observations of solar and/or interstellar D and ^3He can provide an upper bound to the primordial (or, pre-Galactic) abundance of D (Rood, Steigman & Tinsley 1976 ; Dearborn, Schramm & Steigman 1986 ; Yang et al. 1984). Such an upper bound to primordial D leads to a lower bound to η. Of course, solar and interstellar material have been processed through stars in the course of Galactic evolution so that observations of pre-Galactic D would be of great value. Just such - possible - observations of cosmic deuterium in a high redshift, low metallicity QSO absorption system have recently been reported by two independent groups (Songaila et al. 1994 ; Carswell et al. 1994). Although using different telescopes and detectors to observe the $z_{abs} = 3.32$ absorption system towards the $z_{em} = 3.42$ quasar 0014 + 813, both collaborations derive a deuterium abundance (D to H (hydrogen) ratio by number) of $(D/H)_{OBS} \approx 25 \times 10^{-5}$. However, it has been noted[7] that there is significant probability that what has been identified as a deuterium feature could, in fact, be a low column density interloper (a $Ly\alpha$ system at a velocity

shift of 80 kms^{-1} with respect to the main absorber). It is my goal here to show that this latter possibility is most likely correct by demonstrating the incompatibility of such a large D/H ratio with solar system observations of D and ^3He. Such an approach has the virtue of avoiding any prejudice concerning BBN (standard, inhomogeneous or otherwise). Nonetheless, the cosmological implications of these observations, if they really were due to D, are interesting and are discussed, briefly, next.

Assume for the moment that D has been detected in a nearly primordial (high redshift, low metallicity) system. The inferred D/H ratio should place a lower bound on the primordial abundance; since D is only destroyed subsequent to BBN, $(D/H)_{BBN} \geq (D/H)_{OBS}$. For $(D/H)_{BBN} \geq 25 \times 10^{-5}$, $\eta_{10} \leq 1.5$ (Walker et al. 1991) and the corresponding contribution of nucleons to the overall density of the Universe (as measured by the nucleon density parameter Ω_N and the present value of the Hubble parameter $h_{50} \equiv H_0/50kms^{-1}Mpc^{-1}$) is limited to: $\Omega_N h_{50}^2 \leq 0.022$. Even for $H_0 \geq 40kms^{-1}Mpc^{-1}$, this places a severe upper bound on the nucleon density ($\Omega_N \leq 0.034$), strengthening the BBN case for non-baryonic dark matter. What of the BBN abundances of the other light elements? With decreasing nucleon density the primordial yield of ^4He decreases and that of ^7Li increases. For $\eta_{10} \approx 1.5$, $(^7Li/H)_{BBN} \approx 2.3$ which is comparable to the upper bound inferred from observations of lithium in the most metal-poor Pop II stars (Walker et al. 1991). And, such a low value of η actually improves the consistency between the BBN predicted yield of ^4He and the primordial abundance inferred from observations of very low metallicity, extragalactic HII regions. The observations suggest a primordial mass fraction of ^4He, $Y = 0.23 \pm 0.01$ (Olive, Steigman & Walker 1991) while, for $\eta_{10} \approx 1.5$,

$Y_{BBN} \approx 0.231$. Thus, the low value of η implied by a large primordial abundance of D is entirely compatible with the observed abundances and the BBN predicted yields of ^4He and ^7Li (and, ^3He as well).

However, as I shall now show, it is very likely that extragalactic deuterium has not yet been detected. The problem lies in the comparison between the very large abundance inferred from the QSO observations $\left((D/H)_{OBS} \approx 25 \times 10^{-5}\right)$ and the much smaller solar system and interstellar medium abundances (Walker et al. 1991 ; Geiss 1994) ($(D/H)_\odot = 2.6 \pm 0.9 \times 10^{-5}$; $(D/H)_{ISM} = 1.6 \pm 0.2 \times 10^{-5}$). Consistency among these data would require large destruction of D in the course of Galactic evolution. But, since D is burned in stars to ^3He and some ^3He survives stellar processing, this would imply an enhanced abundance of ^3He. To make this quantitative, let us concentrate on the solar system where meteoritic, lunar and solar wind data provide statistically accurate estimates of both the D and ^3He abundances in the pre-solar nebula (Geiss 1994).

Neglecting any net stellar production of ^3He as well as any contribution from primordial ^3He (to maximize our bound), Yang et al.(1984) derived the following inequality which we apply to the solar system,

$$\left(\frac{D +^3 He}{H}\right)_{BBN} \leq \left(\frac{D}{H}\right)_\odot + \frac{1}{g_3}\left(\frac{^3He}{H}\right)_\odot. \tag{1}$$

In equation (1) there are no assumptions concerning BBN and, the only dependence on Galactic evolution enters through g_3, the stellar survival fraction of ^3He(Dearborn, Schramm & Steigman 1986). Equation (1) is a simple reflection of the result that, since D burns to ^3He, the observed abundances of D and ^3He provide an upper bound to the sum of the primordial abundances of D plus ^3He. Since, here, we are interested in bounding

primordial D and, $D/H \leq (D +^3 He)/H$,

$$(D/H)_{BBN} \leq (D/H)_\odot + g_3^{-1}\,(He/H)_\odot\,. \tag{2}$$

The stellar models of Dearborn, Schramm and Steigman (1986) suggested that $g_3 \geq 1/4$ and this is confirmed by the galactic evolution calculations of Steigman and Tosi (1992) who, for a range of different models, found $1/3 \leq g_3 \leq 1/2$. Using the Geiss (1994) solar system abundances and $g_3 \geq 1/4$, we derive an upper bound to the BBN abundance of D.

$$10^5 (D/H)_{BBN} \leq 8.6 \pm 1.5 \tag{3}$$

Here lies the problem with the interpretation of the observed QSO absorption feature as due to D. If correct, we should have $(D/H)_{OBS} \leq (D/H)_{BBN}$. Instead, we find that $(D/H)_{OBS}$ exceeds the upper bound on $(D/H)_{BBN}$ by nearly a factor of three. Put another way, the solar system bound on the BBN abundance is smaller than the inferred abundance in the QSO absorption system by some 12 sigma. The large value of $(D/H)_{OBS}$ could only be compatible with the low solar system abundances of D and ^3He if the ^3He survival fraction has been significantly overestimated (Dearborn, Schramm & Steigman 1986 ; Steigman & Tosi 1992); consistency is only obtained for $g_3 \leq 0.09 \pm 0.02$, which is some 8 sigma away from the standard lower bound (Dearborn, Schramm & Steigman 1986) of $g_3 \geq 0.25$.

If, indeed, this absorption feature is not due to intergalactic deuterium, what is it? As Carswell et al. (1994) have noted, the probability that any single measurement is confused with hydrogen absorption is high ($\sim 15\%$). The observed feature could be from hydrogen absorption in a low column density cloud along the same line of sight, displaced in velocity

from the main absorber by 80 kms^{-1}. Thus, any such observation can only place an upper bound on the pre-Galactic D-abundance. Although it is likely that nearly primordial D is yet to be observed, the capability of current telescopes and detectors to achieve such an important observation is clear. The observers are to be commended and encouraged to press on.

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